Study of Environmental Emissions from Road Transportation; A case of Bhaktapur Municipality, Nepal

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Abstract

The unprecedented growth of emissions has deteriorated air quality dramatically leading to a pulmonary complication in human health. Especially during the winter season, the prevalence of Chronic Obstructive Pulmonary Diseases (COPD) increases more in females compared to males. Selecting different peak and non-peak hours, this study estimated vehicular emission load with the help of emission factors, derived equations, field visits, and literature review. The average annual vehicular energy demand of Bhaktapur Municipality was estimated at 33,044 GJ while the emission load was estimated at 3,310 tons/year, including (CO2, CO, NOx, HC, and PM10) of which CO2 accounts for 94.36% of total emissions followed by CO (4.39%), HC (0.72%), NOx (0.35%), and PM10 (0.18%), respectively. Statistical analysis showed significant positive correlation ($r = 0.92$, $p = 0.002$) between CO2 and PM10, ($r = 0.87$, $p = 0.009$) between CO2 and NOx, ($r = 0.90$, $p = 0.004$) between CO and HC, ($r = 0.74$, $p = 0.05$) between NOx and PM10, respectively. Assuming an inauguration of electric vehicles (Cars, Motorbikes, and Buses) within the Municipality at the rate of 10%, 20%, and 30%, showed a significant reduction in emissions by 157, 314 and 471 tons/year, respectively. The CO2 was found more potent to deteriorating air quality in the future compared to other vehicular pollutants. Despite lower emission load in Bhaktapur Municipality compared to its nearest adjacent city Kathmandu, exponential growth in emissions can become inevitable in the future if clean energy is not promoted in time.

STUDY OF ENVIRONMENTAL EMISSIONS FROM ROAD TRANSPORTATION: A CASE OF BHAKTAPUR MUNICIPALITY, NEPAL

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INTRODUCTION

1. Main sources of air pollution are brick kilns, motor vehicles, and construction activity (Dhakal, 2006).
2. Pedestrians are more exposed to pollutants due to their close proximity towards vehicular emissions (pacitto et al, 2019).
3. In 2016, an estimated 16,302 people died from COPD in Nepal of which death rate due to COPD in female was 119.7 per 100,000 people compared to male comprising death rate of 102.6 per 100,000 people (Adhikari et al., 2018).
4. Study shows 24,000 premature annual deaths are expected to be happened in Nepal by 2030 due to outdoor air pollution (Shindell, 2012).
5. In 2017, COPD occupy second position while ranking most causative factors to trigger deaths in Nepal (IHME, 2018).
6. In Nepal, COPD was the common cause of mortality between year of 2013 to 2014 (DOH, 2014).

OBJECTIVES

General
- Study of environmental emissions from road transportation.

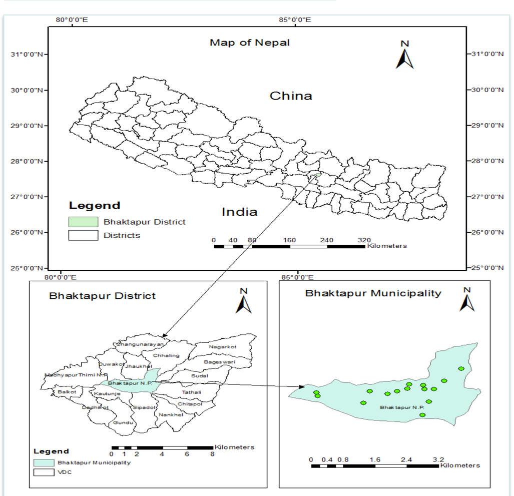
Specific
- To estimate annual vehicular energy demand in Gj.
- To estimate vehicular emission load in tons/year.

LIMITATIONS

- No instruments were used for the measurement of Vehicular emissions.

METHODOLOGY

Study Area



- Bhaktapur municipality lies in the east corner of Kathmandu valley, about 13 km from the capital city having 10 administrative wards.
- The municipality occupies area of 6.89 sq. km with population 83,658 (Census, 2011).
- The GPS coordinates were generated from earth explorer in a stratified random manner considering the road junction and traffic movement which were then represented using GIS (Geographical Information System) (figure1).

Figure 1: Map of Study area

Methods

1. Field data were collected in the year 2018 in the month of March from 15 coordinates located on the map of Bhaktapur Municipality (Figure 1).
2. The Two-hour peak from 8 am to 10 am and Two-hour non-peak from 1 pm to 3 pm, in total 4 hours was taken for the count of private vehicles for a month whereas recorded data of commercial vehicles were retrieved from its respective vehicle committee.
3. The average annual vehicle kilometer (VKT) for each vehicle types was calculated by measuring average aerial distance from each GPS points to its nearest border multiplied with average vehicles trip per day, taking their different driving routes into account. Similarly, the fuel economy (mileage) of each vehicle type was obtained from a field survey using a random sampling method (Table 1).

Table 1: Total number of Vehicles (by types) plying on road with their average annual kilometer and fuel economy in Bhaktapur Municipality

Vehicle Types	Fuel Types	Total Number of Vehicles (Ni,t)	Average Annual Vehicle Kilometre (VKT i,t) in Km	Fuel Economy (F_i) in l/km
Mega Bus	Diesel	20	2016.26	0.28
Mini Bus	Diesel	201	2923.58	0.25
Car/Van	Gasoline	448	2243.09	0.07
Pickup Van	Diesel	212	4738.21	0.15
Mini Truck	Diesel	135	8417.89	0.25
Motor Bike	Gasoline	2212	2893.33	0.02
Others (Tractors/ Micro bus)	Diesel	55	6502.44	0.16

Gaseous pollutants like Carbon dioxide (CO_2), Carbon Monoxide (CO), Nitrogen Oxides (NOx), hydrocarbon (HC), and particulate matter of 10 microns or less (PM_{10}) were taken in the study as emission factors of these pollutants are available in a published article (Dhakal, 2006) (Table 2).

Table 2: Emission factors (amount of pollutants emitted per unit distance travelled) expressed in gram per liters.

Vehicle types	Fuel Types	CO_2	CO	NOx	HC	PM_{10}
Mega Bus	Diesel	3440	24	35.61	11.1	11.7
Mini Bus	Diesel	3440	24.8	11.2	10.4	8.1
Car/Van	Gasoline	3985	261.9	29.6	87.9	2.27
Pickup Van	Diesel	3440	24.8	11.2	10.4	7.2
Mini Truck	Diesel	3440	24.8	11.2	10.4	8.1
Motor Bike	Gasoline	3766	726.3	11.3	69.9	4.3
Others(Tractors/Micro Bus)	Diesel	3440	24.8	11.2	10.4	7.2

- Mathematical equations (Equation 1 and 2) used in the published article (Bajracharya & Bhattarai, 2016) were adopted for the estimation of vehicular energy demand and emission load:

Equation 1: Equation for Energy demand estimation

$$EDi,t = Ni,t * VKTi,t * Fi \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (i)$$

Where EDi,t is total annual energy demand in liters by each vehicle type i in a year t.

Ni,t is total number of existing vehicles in year t.

VKTi,t is average annual mileage in kilometer

Fi is average fuel economy in liters per kilometer

Equation 2: Equation for Emission load estimation

$$Ej,i,t = EDi,t * EFj,i,t \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (ii)$$

Where Ej,i,t is total emission of emission type j by vehicle type i in year t.

EDt,i is total energy demand by vehicle type i in year t.

EFj,i,t is emission factor of type j expressed in gram per liters of vehicle type i in year t.

RESULTS

The average annual energy demand estimated with the help of (equation 1) and annual emission load estimated with the help of (equation 2) for each vehicle (by types) are tabulated in (Table 3) and (Table 4) and are represented in (figure 2) and (figure 3) respectively.

Table 3: Average annual energy demand estimated in Giga Joule (Gj)

Vehicle types	Energy Demand $Ed_{i,t}$ (Gj)	Energy Demand $Ed_{i,t}$ (Gj) in percentages
Mega Bus	445	1 %
Mini Bus	5671	17 %
Car/Van	2546	8 %
Pickup Van	5965	18 %
Mini Truck	10966	33 %
Motor Bike	5150	16 %
Others(Tractors/Micro Bus)	2301	7 %
Total	33044	100 %

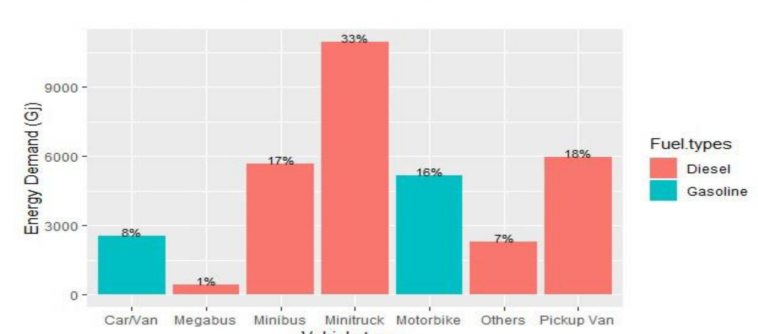


Figure 2: Average annual energy demand of each vehicle (by types) distinguished by fuel types

Average annual energy demand was found to be 33,044 Giga Joule (Gj) of which Mini Truck accounts for 33% of total energy demand which is highest of all, followed by Pickup Van (18%), Mini Bus (17%), Motorbike (16%), Car/Van (8%), others (7%) and Mega Bus (1%) respectively.

Table 4: Vehicular emission load (by types) estimated in tons/year

Vehicle types	Fuel Types	CO_2	CO	NOx	HC	PM_{10}	Total	Total %
Mega Bus	Diesel	39.63	0.28	0.41	0.13	0.13	40.58	1 %
Mini Bus	Diesel	505.37	3.64	1.65	1.53	1.19	513.38	16 %
Car/Van	Gasoline	296.63	19.50	2.20	6.54	0.17	325.04	10 %
Pickup Van	Diesel	531.61	3.83	1.73	1.61	1.11	539.90	16 %
Mini Truck	Diesel	977.32	7.05	3.18	2.95	2.30	992.80	30 %
Motor Bike	Gasoline	567.12	109.37	1.70	10.53	0.65	689.37	21 %
Others	Diesel	205.04	1.48	0.67	0.62	0.43	208.24	6 %
Total		3122.73	145.14	11.54	23.91	5.98	3310	100%
Total %		94.36 %	4.39%	0.35%	0.72 %	0.18%	100%	

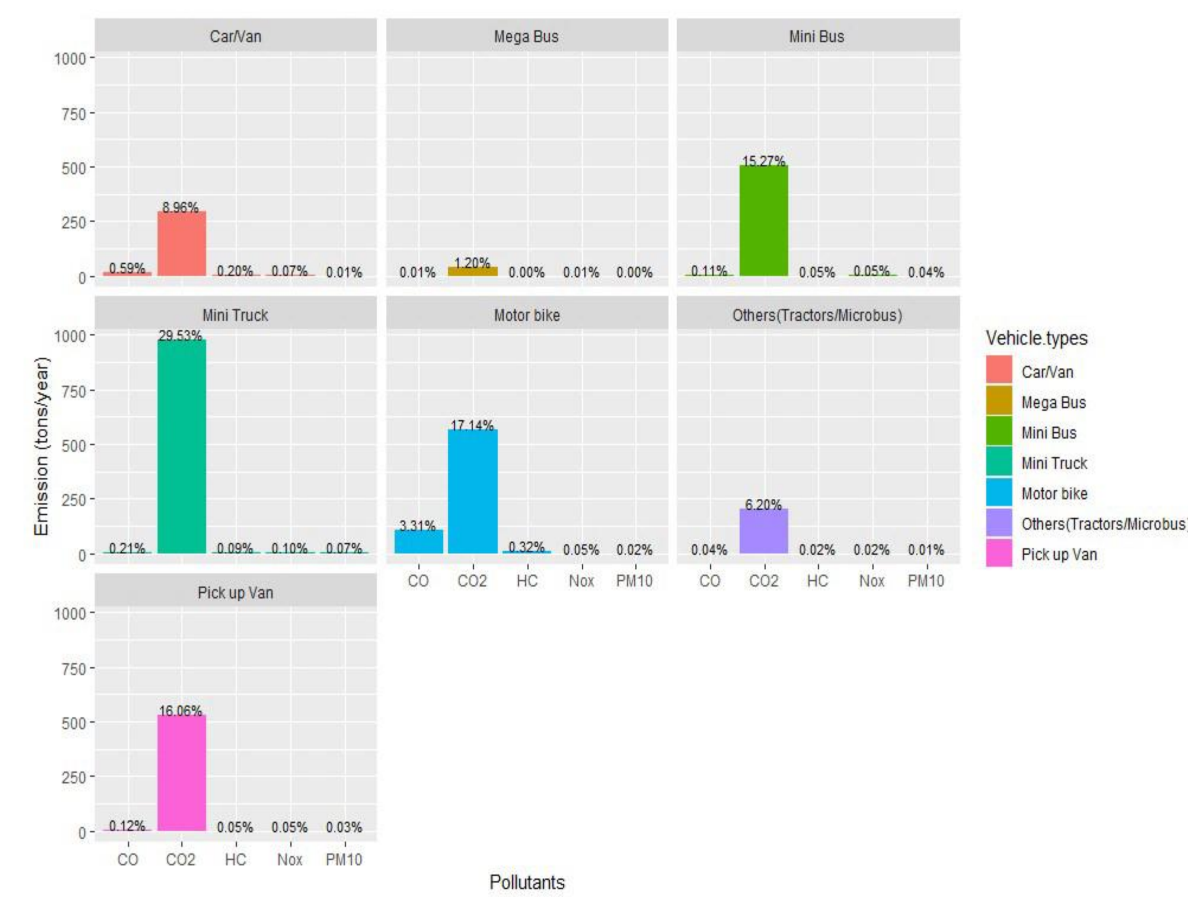


Figure 3: Vehicular emission load (by types) in percentages

- Mini Truck found to have highest CO_2 emission accounting by 29.53% followed by Motorbike (17.14%), Pickup Van (16.06%), Mini bus (15.27%), Car/Van (8.96%), Others (6.20%) and Mega Bus (1.20%) respectively (figure 3).

Table 5: Share of vehicular pollutants (by fuel types) given in tons/year

Fuel types	CO_2	CO	NOx	HC	PM_{10}	Total
Diesel	2258.98	16.28	7.64	6.84	5.17	2294.89
Gasoline	863.75	128.87	3.91	17.07	0.82	1014.41
Total	3122.73	145.14	11.54	23.91	5.98	3309.31

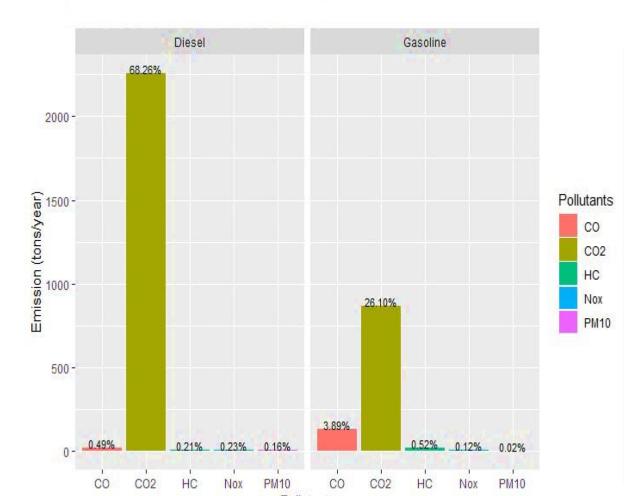


Figure 4: Share of vehicular pollutants (by fuel types) in percentages

- Diesel fuel found to have a maximum share of CO_2 emission accounting for 68.26% of total emissions followed by CO (0.49%), NOx (0.23%), HC (0.21%) and PM_{10} (0.16%), respectively.
- On the other hand, gasoline fuel found to have a maximum share of CO_2 emission accounting for 26.10% of the total emissions followed by CO (3.89%), HC (0.52%), NOx (0.12%) and PM_{10} (0.02%), respectively (Figure 4).

Table 6: Potential changes in total emissions due to introducing electric vehicle at different rates

Introducing electric Cars, Motorbikes and Bus By	Emission estimated in our study (tons/year)	Emission after the launch of electric vehicles- Buses, Cars, and Motorbikes (tons/year)	Difference (tons/year)
10%	3309.31	3152.47	156.84
20%		2995.63	313.68
30%		2838.79	470.52

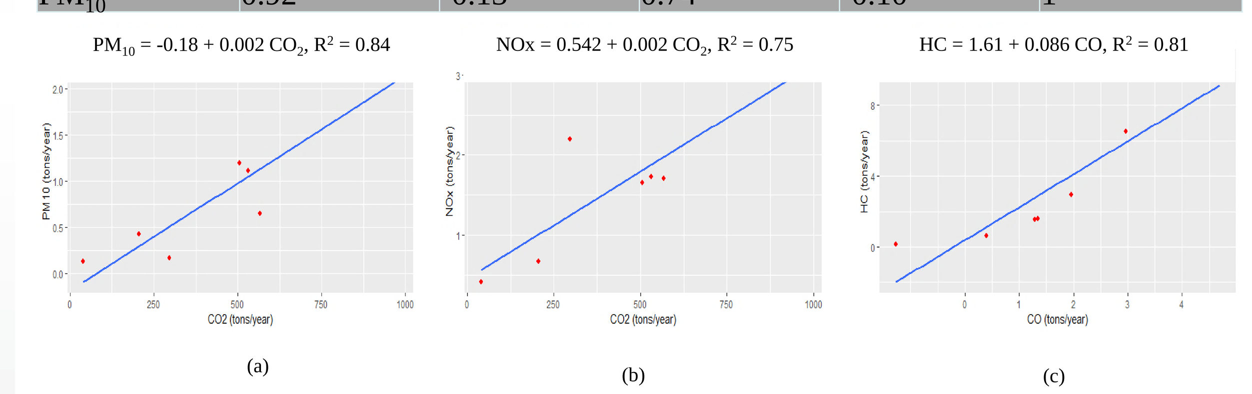
- Introducing electric vehicles at the rate of 10%, 20% and 30% shows significant reduction in amount of vehicular emissions in a year (table 6).

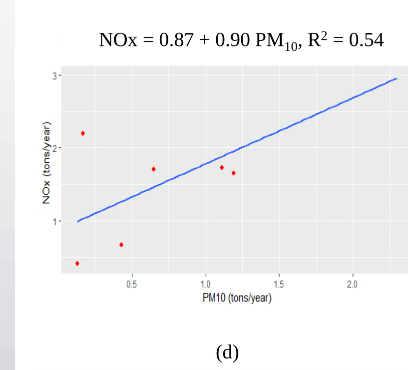
STATISTICAL ANALYSIS

- The correlation matrix (Table 7) shows both positive and negative correlations among pollutants under study.

Table 7: Correlation Matrix among various pollutants

	CO_2	CO	NOx	HC	PM_{10}
CO_2	1				
CO	0.19	1			
NOx	0.87*	0.11	1		
HC	0.27	0.90*	0.38	1	
PM_{10}	0.92*	-0.13	0.74*	-0.10	1





Pearson product-moment correlations performed between CO_2 and PM_{10}, CO_2 and NOx, CO and HC, NOx and PM_{10} (r = 0.92, p = 0.002), (r = 0.87, p = 0.009), (r = 0.90, p = 0.004), (r = 0.74, p = 0.05) were found positively correlated and statistically significant at 5% level of significance (figure 5a, 5b, 5c and 5d).

Figure 5: Scatter plot diagram showing the linear relationship (a) between CO_2 and PM_{10}, (b) relationship between CO_2 and NOx, (c) relationship between CO and HC, (d) relationship between PM_{10} and NOx

CONCLUSION

- Annual energy demand of Bhaktapur Municipality for a year of 2018 was estimated 33,044 GJ and vehicular emission load including pollutants CO_2, CO, NOx, HC and PM_{10} was estimated 3310 tons/year.
- Diesel fuel found to have maximum share of CO_2 emissions compared to Gasoline fuel. CO_2 was found more potent to deteriorating air quality in the future compared to other vehicular pollutants.
- Introducing electric car, motorbike and Buses showed a significant reduction in emissions.
- Alternative practices relying on clean energy if inaugurated in time can prevent worse future scenario.

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